Future G-ray Missions: A Community Roadmap

Future Space-Based Gamma-ray Observatories Workshop
25 Mar 2016

Terri Brandt
NASA / Goddard

Gamma-ray Community Roadmap:

Purpose:

- Support planning for the 2020 **Decadal**
- Serve as a reference for all gamma-ray proposals
- Enable deeper connections **within** and **between communities**
- Articulate a common vision for the space-based gamma-ray community

The roadmap will:

- Define compelling, enduring **themes** linking **science objectives**
- Define instrument requirements
- Summarize possible mission concept(s)

by:

- Painting a landscape
- Showing how gamma-ray astrophysics naturally forms a key component

Gamma-ray Community Roadmap:

Gamma-ray Surveyor:

The roadmap will:

- Define compelling, enduring **themes** linking **science objectives/topics**
- Define instrument requirements
- Summarize possible mission concept(s)

by:

- Painting a landscape: **Multimessenger and Time Domain Astrophysics?**
- Showing how gamma-ray astrophysics naturally forms a key component

with a context obtained by:

- Compiling compelling science topics that can be accomplished by keV to GeV and higher energy instruments for launch by NASA.
- Flowing theme(s) and science topics into instrument requirements for reference by community and reviewers alike.

Ensure the greatest breadth and accuracy through community input!

Gamma-ray Surveyor:

The roadmap will:

- Define compelling, endurin
- Define instrument re
- Summarize pos

by:

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- Show **y** astrophysics natur **onent**

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E **through community input!**

Science Goals:

What are the key science questions in the following areas?

- X-Ray Binaries
- Pulsars / Magnetars
- SNR / PWNe
- Classical Novae
- Supernovae
- Active Galactic Nuclei
- Diffuse Galactic Emission
- Cosmic Diffuse Emission
- Gamma Ray Bursts
- Fundamental Physics and Dark Matter
- Solar Physics
- Terrestrial Gamma Flashes

Leverage work already done for AstroMeV! http://astromev.in2p3.fr/

- **What other topics should be included for completeness?**
- **Ideas for other key linking themes?**
  - Eg: To better understand the origins and evolution of the universe and everything in it through study of high energy particles.
- **What other science topics are connected, at any energy?**

Instrument Requirements:

What are the **necessary** instrument requirements?
What are the **desired** requirements?
Where do the requirements overlap?

Capturing as:

Spatial:		**Spectral:**		**Sensitivity:**
Coverage	Resolution (deg)	Energy Range	Resolution	Line/ Continuum

Timing?	**Polarization?**	**Real-time Capability?**

Leverage work already done for AstroMeV! http://astromev.in2p3.fr/

Current Table!

GammaSIG: Science Topics, Science Requirements, and Instrument Requirements Tables

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	A	B	C	D	E	F	G	H	I	J
1	This table collects all the scien	e topics brainstormed for future orbiting gamma-ray mission(s), and the science requirements which flow from the science topics.								
2	Each science topic should have a	s many subtopics as necessary to encompass the range of ideas.								
3	Each subtopic should have two	rows: the first listing the minimal requirement to make progress on the topic and the second listing the goal.								
4	Please fill out the science (sub)	topics and update any missing or uncertain information.								
5	If you disagree with some topic or	information, please leave a comment for discussion!					Example	View: hover on yellow box corner for comment. Inser		
6										
7		Spatial:		Spectral:		Line/Continuum				
8	Topic	Coverage	Resolution (deg)	Energy Range	Resolution	Sensitivity (erg cm^-2 s^-1)	Timing?	Polarization?	Real-time Capability?	
9	SNRs:									
10	Particle populations	5-10deg	~0.1	MeV-GeV	~<25%	~10^-11				
11		All-sky	~<0.05	MeV-TeV	~<15%	~10^-13	0.1-3ms (remove pulsar)			
12	Shell	~5deg	~<0.05?	MeV-GeV?	~<25%	~10^-11				
13		All-sky	~<0.01	MeV-GeV?	~<15%	~10^-13	0.1-3ms (remove pulsar)	<20%?	(X-ray scale ~ years)	
14	Escape	5-10deg	~0.2	MeV-GeV	~<25%	~10^-12				
15		All-sky	~<0.1	MeV-TeV	~<15%	~10^-14	(remove pulsar??)			
16	44Ti lines	5-10deg	~0.05?	keV-1.157MeV	~<0.4%?	~10^-6? phot/cm2s				
17		All-sky	~<0.01	keV-1.157MeV	~<0.2%	~10^-7 phot/cm2s				
18	*What else?*									
19										
20	PWNe:									
21	Spectral Cutoffs	5-10deg	~<0.1	MeV	~<20%	~10^-11				
22		All-sky	~<0.01	keV-MeV	~<10%	~10^-12	0.1-3ms (remove pulsar)			
23	B-field Geometry	Crab	~<0.05?	~MeV	~<25%	~10^-12?		10%		
24		+ others	~<0.01	~MeV	~<15%	~10^-13?		0.20%		

4 Science Requirements | Instrument Specs | Topic Key Members

https://docs.google.com/spreadsheets/d/12AHH5oOJO8NDu1FY3H1h3hclZBndGe8oJh-8vJBI8AE/edit?usp=sharing

Science Goals:

What are the key science questions in the following areas?

- **X-Ray Binaries** (Tomsick)
- Pulsars / Magnetars (Baring, Harding)
- SNR / PWNe (Brandt, Hewitt)
- Classical Novae (Cheung, Comiuk)
- **Supernovae** (Boggs, Grefensette, Leising)
- **Active Galactic Nuclei** (Falcone, Finke, Madejski, Ojha)
- **Diffuse Galactic Emission** (Digel, Hartmann, Moskalenko)
- **Cosmic Diffuse Emission** (Ajello, Venters)
- **Gamma Ray Bursts** (Connaughton, Omodei, Zhang)
- Fundamental Physics and Dark Matter (Buckley, Caputo, Krawczynski, A. Smith)
- Solar Physics (Murphy, Pesce-Collins, Ryan)
- **Terrestrial Gamma Flashes** (Briggs, Dwyer, Grove, D. Smith)

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What are the key science questions in the following areas?

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Ensure the greatest breadth and accuracy through your input!

Leverage work already done for AstroMeV! http://astromev.in2p3.fr/

Mission Concepts:

Straw missions:

- Abstract missions with notional platforms, technologies, and costs
- Drawn from the set of science goals and instrument requirements

Missions in development:

Drawn from current community efforts, with:

- defined science objectives
- defined instrument requirements
- defined technologies
- defined platform and cost cap

Mission Concepts:

GammaSIG: Science Topics, Science Requirements, and Instrument Requirements Tables

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	A	B	C	D	E	F	G	H
1	**Mission**	**Energy Range [MeV]**	**Energy Resolution [DE/E]**	**Angular Resolution [deg]**	**FOV [sr]**	**Flux Sensitivity [MeV cm-2 s-1]**		
2	**TPCs (polarimetry)**							
3	AdEPT	5-200	~30% @ 70 MeV	~0.6 @ 70 MeV	~2 pi	<3e-5		
4	LArGO	0.1-10^5	~3% @ 1 MeV	~1 @ 100 MeV	large (>2.5)			
5	HARPO	1-100	(6/15/30)% @ 1/10/100 MeV	~0.3 @ 40 MeV	4pi ?	<1e-6	Denis Bernard: NIM A 729 (2013)	
6	ASCOT	1ish						
7								
8	**Spectrometers/Mappers**							
9	GRX/COSI	0.2-few	(1/0.1)% @ 0.2/1 MeV	~4 @ 1 MeV	3.14	<2e-5		
10								
11	**Continuum/Survey mapper**							
12	AstroGAM	0.3-100	(1/7)% @ 1/10 MeV	~1 @ 100 MeV	~2.6	<6e-6		
13	ComPair	0.3-200	(2/4/12)% @ 1/10/100 MeV	~(7/1) @ 1/100 MeV	3.5	<2e-6		
14								
15	**Current (for a benchmark)**							
16	Fermi-LAT	20->3e10^5	(18/7)% @ 100/1000 MeV	~(3/0.04) @ 100(10000) MeV	~2.5	<1e-6		
17								
18	DAMPE (launche	5 GeV – 10 TeV	1% at 800 GeV	0.1° at 100 GeV	~0.3 m^2 sr	lower than LAT: http://lanl.arxiv.org/abs/1407.4866		(for g-rays)
19								
20	**This is not a complete list, feel free to add additional instruments that have been left off							
21								
22								
23								
24								
25								
26								
27								
28								

Science Requirements | Instrument Specs | Topic Key Members

Please add your instrument concept to and/or update the table!

Technology Requirements:

The table will also help identify and motivate new technologies for strategic investment to enable us to build instruments that meet the requirements.

Strategic Astrophysics Technology (SAT) Awards

The Astrophysics Division (APD) at NASA Headquarters solicits proposals under the Strategic Astrophysics Technology/Technology Development for Physics of the Cosmos (SAT/TPCOS) program to mature key technologies for implementation in space flight missions. Selection of proposals for funding under the TPCOS 2010 solicitation were made based on the following factors: (1) the overall scientific and technical merit of the proposal; (2) the programmatic relevance of the proposed work; and (3) the cost reasonableness of the proposed work.

http://pcos.gsfc.nasa.gov/technology/strategic-technology-awards.php

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Next Steps?

Agree on themes?

Finalize science objectives and instrument requirements.

Practicalities for writing:

- Identify committed writers
- Outline sections
- Compile Draft
- Obtain community feedback

Contents

- Science Goals:
  What are the outstanding science issues that should be addressed?
- Instrument Requirements:
  What are the instrument requirements needed to address the science goals?
- Technology Requirements:
  What new technologies will be required?
- Straw Mission Concepts:
  How many missions would be required? What might they look like?
- Specific Mission Concepts:
  What are some of the specific mission concepts being investigated by community members?

Goal is to complete the roadmap in the fall.

Theme: SNRs, …

To better understand the origins and evolution of the universe and everything in it through study of high energy particles,

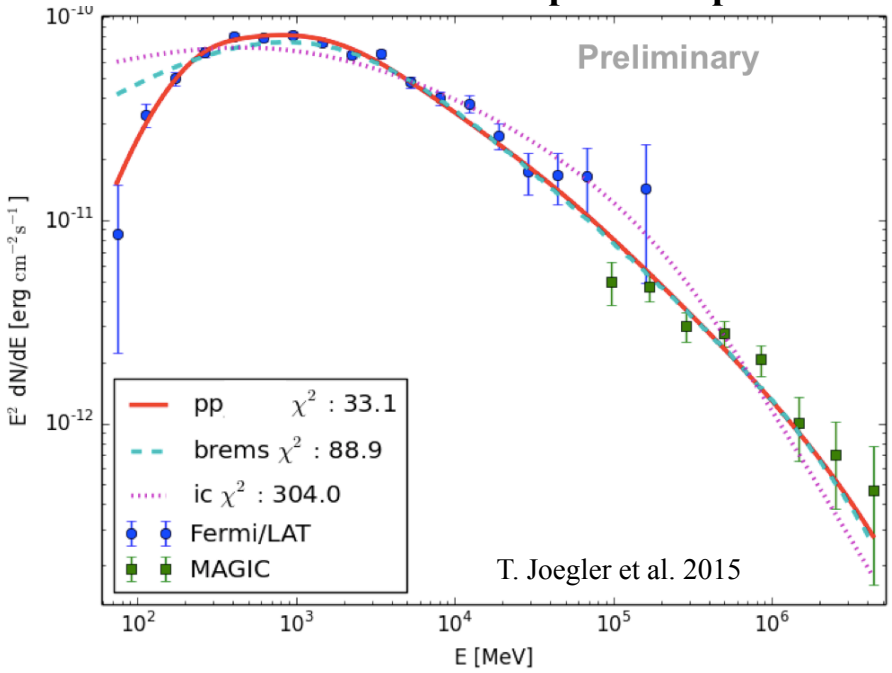
- to understand the fundamental physics of acceleration in a variety of systems and
- to understand particles' interaction with, propagation through, and impact on environments at all scales (local, galactic, and extragalactic)

Discrepancies with predictions will indicate the need for new particles and/or fundamental physics. (See Regina's talk!)

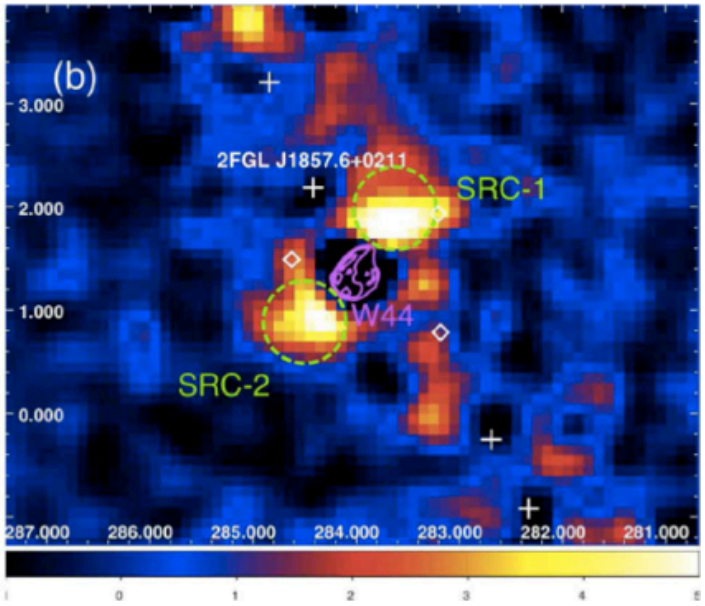
Science Topics: SNRs

Most likely largest contributors of energetic particles sculpting galaxies…

W51C: 3rd SNR w evidence of pion bump

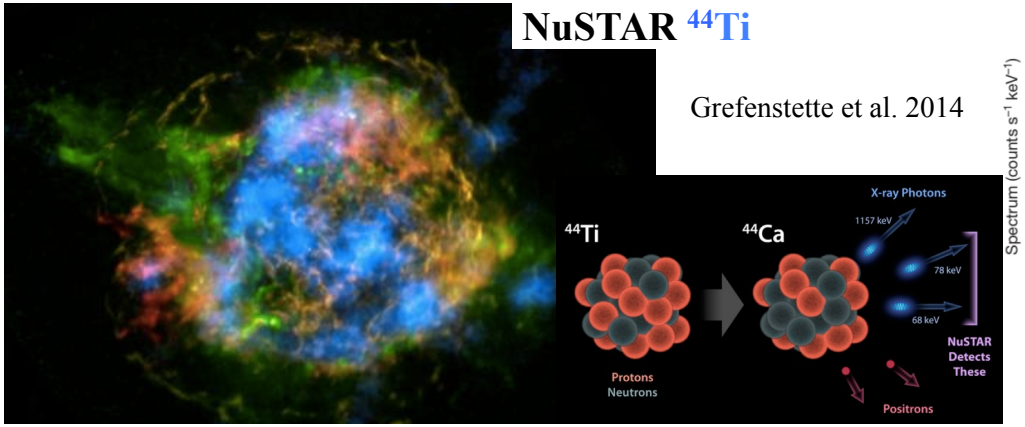


W44: Particle escape? Shocked cloud?

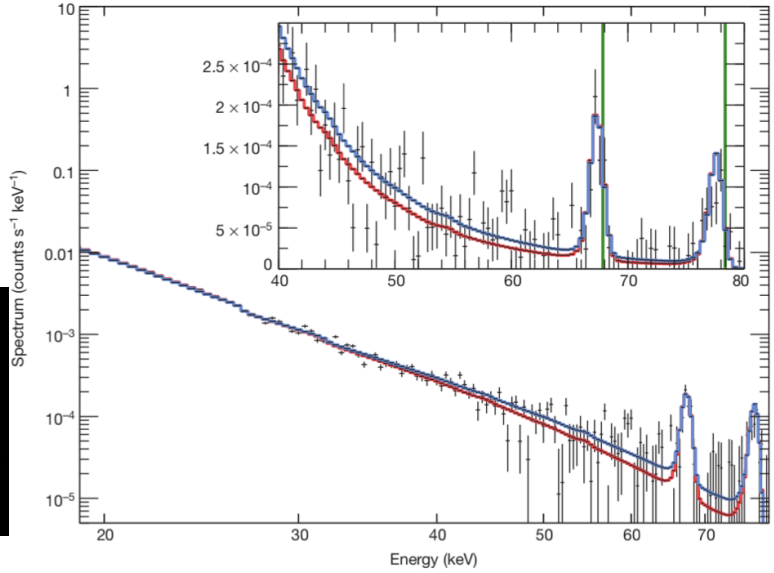


Uchiyama et al. 2012 ApJ 749, L35

NuSTAR ^{44}Ti



Grefenstette et al. 2014



Science Topics: SNRs

Most likely largest contributors of energetic particles sculpting galaxies…

- Constrain hadronic and leptonic particle populations' number and energy distributions
  - via spectral decomposition of spatially well-resolved remnants (MeV, GeV-TeV)
  - connect to direct cosmic ray measurements!
    - constrain CR origins
    - link to their impact on galaxies' physical and chemical evolution
- Resolve shell structure to
  - observe acceleration processes and
  - connect w MW data more directly (filaments, B-fields, …).
  - Connection to progenitor type through shape?
- Measure gradients in emission (given a known photo-particle background) to constrain escape processes.
- ^{44}Ti predictions for Type Ia progenitor possibilities (other than CO white dwarf?)

- Testing a variety of sources (eg progenitor) in a variety of environments will probe more physical processes and help minimize the impact of incomplete (MW) data sets.

Instrument Requirements: SNRs

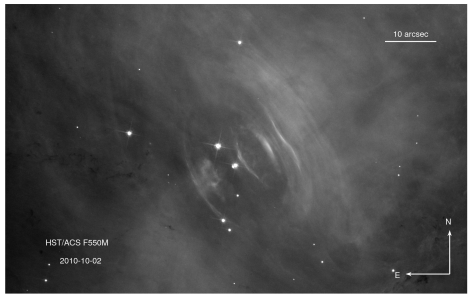
Most likely largest contributors of energetic particles sculpting galaxies…

Topic	Spatial coverage	Spatial resol-ution	Energy range	Spectral resol-ution	Line/ continuum sensitivity	Timing?	Polari-zation	Real-time capability
Particle popula-tions	5-10° / All sky	~<0.05°	MeV – TeV	<~15%	~10^{-13} erg $cm^{-2}s^{-1}$	~0.1-3ms (remove pulsar)		
Shell	~5° / All sky	<0.01°	MeV – GeV?	<~15%	~10^{-13} erg $cm^{-2}s^{-1}$		<20%?	(X-ray scale: ~ years)
Escape	5-10° / All sky	<0.1°	MeV – TeV	<~15%	~10^{-14} erg $cm^{-2}s^{-1}$			
^{44}Ti lines	5-10° / All sky	~0.01°	keV – 1.157 MeV	<0.2%	~10^{-7} phot $cm^{-2}s^{-1}$			
?								

Science Topics: PWNe

Particles accelerated by the wind from pulsars…

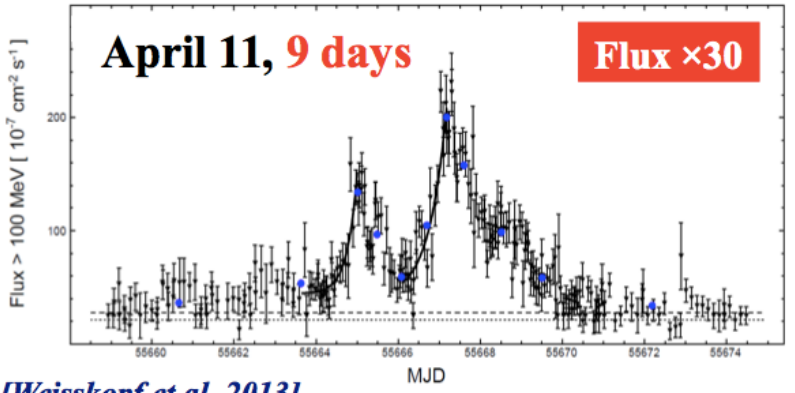
The variable Crab Nebula

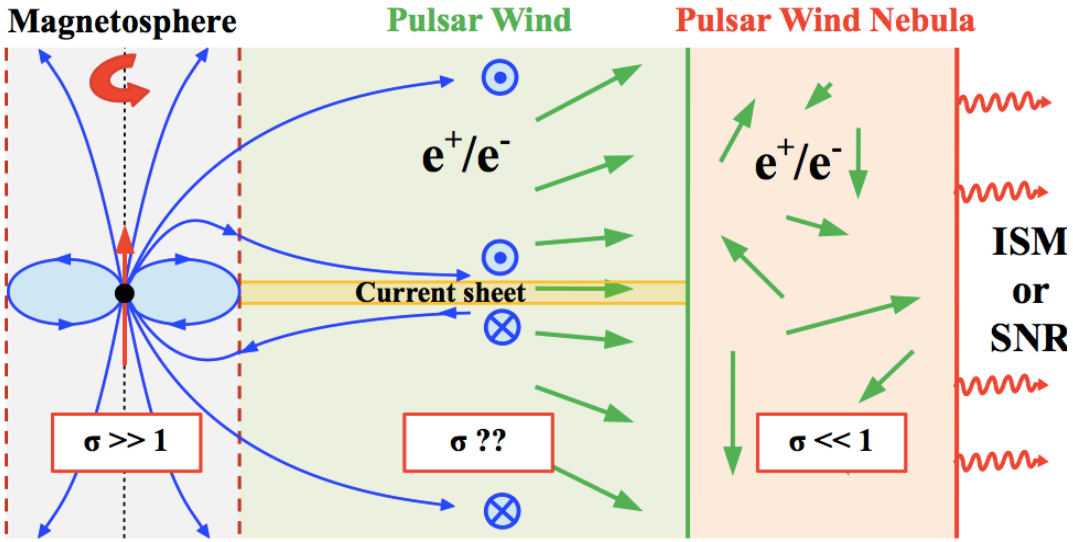


Discovery of MeV-GeV Flares from the Crab!

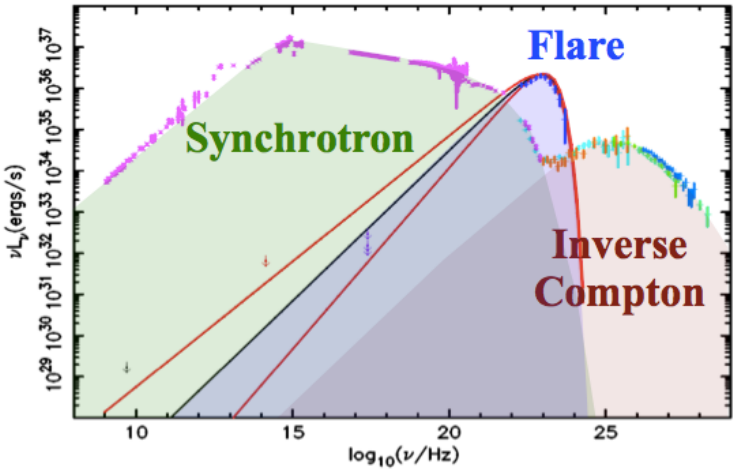
Striped wind simulations explain the "σ problem"

[Buehler et al., 2012]





[Weisskopf et al. 2013]



$$\sigma = \frac{\text{Poynting flux}}{\text{Particle kinetic energy flux}}$$

Transition σ >> 1 to σ << 1 unknown: "sigma" problem

B. Cerutti

Science Topics: PWNe

Particles accelerated by the wind from pulsars…

- Probe particle acceleration in relativistic shocks and associated magnetic field strengths through measurement of spectral cutoff(s) above 100keV (presently little to no data), probing in particular the inner regions where non-dissipative MHD models fail ("σ problem")
- Polarization measurements could constrain the magnetic field geometry in the acceleration region.
- Better understand the physics and origin of the Crab GeV flares by observing any MeV variability around the synchrotron cutoff energy

- Testing a variety of sources in a variety of environments will probe more physical processes and help minimize the impact of incomplete (MW) data sets;
- NB! This is limited due to the relative faintness of PWNe other than the Crab (next brightest are ~2 orders of magnitude lower in flux)

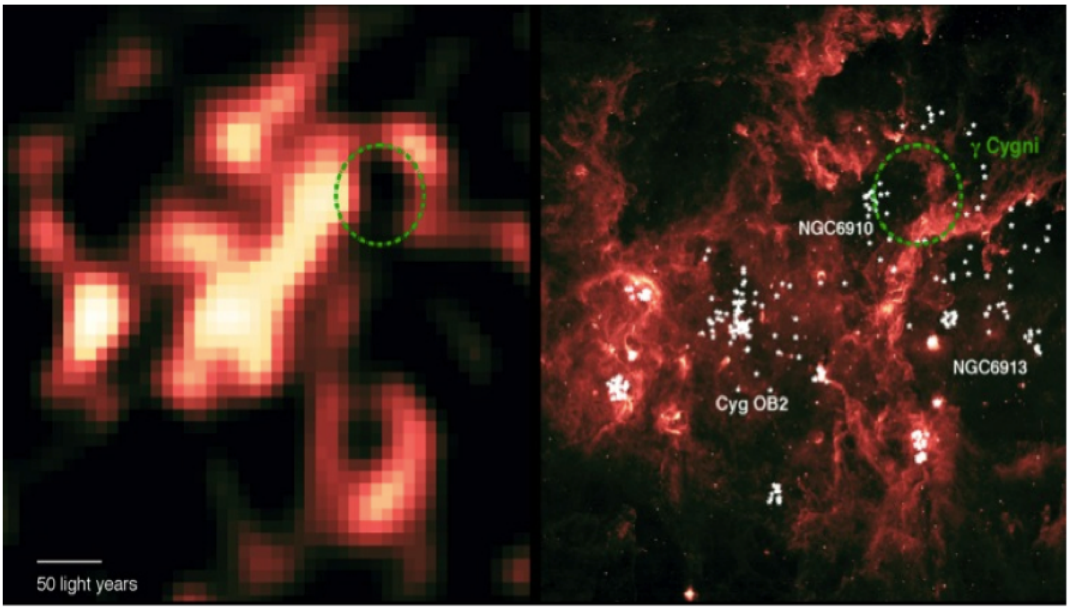
Science Topics: PWNe

Particles accelerated by the wind from pulsars…

Topic	Spatial coverage	Spatial resol-ution	Energy range	Spectral resol-ution	Line/ continuum sensitivity	Timing?	Polari-zation	Real-time capability
Spectral Cutoffs	All sky	~<0.01°	keV – MeV	<~10%	~10^{-12} erg $cm^{-2}s^{-1}$	< 3ms (remove pulsar)		
B-field geometry	Crab, (others)	<0.01°?	~MeV	<~15%	~10^{-13} erg $cm^{-2}s^{-1}$?		10% (0.2%)	
Crab flares	~3°	<0.1°?	~1 MeV – 1 GeV (contemp-oraneous)	<~15%	~10^{-12} erg $cm^{-2}s^{-1}$			Y + MW, Flare ~ few days
?								

Science Topics: Superbubbles

Groups of massive stars…



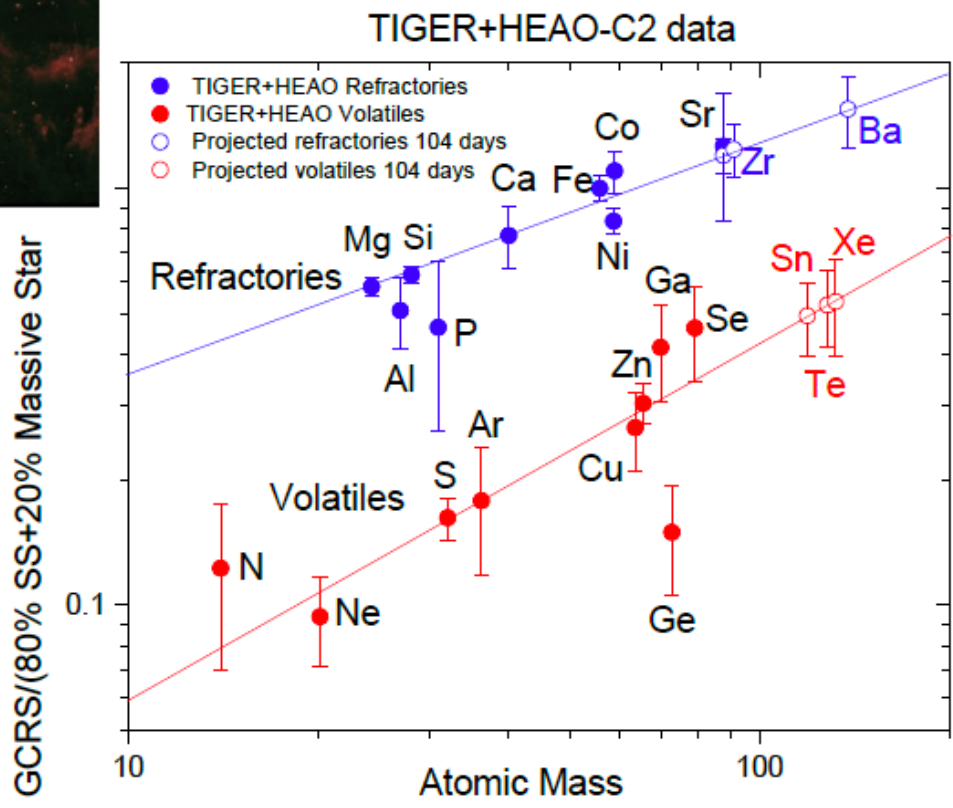
Cocoon of 10-100 GeV γ-ray emission

IR emission from the Cygnus Superbubble

Credit: I. A. Grenier (Fermi LAT/AIM/U. Paris Diderot/CEA) and L. Tibaldo (Fermi LAT/SLAC).

CRs from Massive Stars?

R. Binns et al. ICRC 2013



Science Topics: Superbubbles

Groups of massive stars…

- Trace massive star formation
  - ^{26}Al, ^{60}Fe lines: lifetime of order OB association('s evolution) and independent of local ionization state.
  - energetic particles can seed further star formation in nearby clouds.
- Map the Galaxy's distribution of
  - ^{26}Al, ^{60}Fe lines: trace large scale outflow of particles, energy, and momentum which can significantly affect galaxy evolution.
- Study of the spectral and spatial distribution of continuum emission can address the same particle acceleration and interaction topics as for SNRs in particularly energetic and structured environments (ex: Cygnus cocoon)

Science Topics: Superbubbles

Groups of massive stars…

Topic	Spatial coverage	Spatial resol-ution	Energy range	Spectral resolution	Line/ continuum sensitivity	Timing?	Polari-zation	Real-time capability
^{26}Al, ^{60}Fe lines	~20°^{2} regions, Galaxy	<0.05°	~1-6 MeV	<~10% ; <0.2%* *resolve Doppler broadening	~10^{-7} cm^{-2}s^{-1}MeV^{-1}			
Particle popula-tions	~20°^{2} regions, all sky	<0.1°	MeV – TeV	<~15%	~10^{-13} erg cm^{-2}s^{-1}	Poss. ~<3ms (pulsars)		
?								

Connections to Other Science Topics

To better understand the origins and evolution of the universe and everything in it through study of high energy particles,

- Novae as scaled down SNe/R with more human-accessible time scales
- γ-ray binaries: particle acceleration and associated magnetic field from interaction between a pulsar's relativistic wind and the companion's wind
- Magnetars, rotation-powered pulsars: origin of MeV γ-rays from magnetic fields above Schwinger (QED) limit
- Galactic center as collection of pulsars / SNRs / massive stars / …
- Low energy CR nuclear lines from interactions in ISM/clouds (eg ^{12}C, ^{16}O => 4.4, 6.1 MeV)
- …
- Discrepancies indicate need for new particles and/or physics!

Testing a variety of sources (eg progenitor) in a variety of environments will probe more physical processes and help minimize the impact of incomplete (MW) data sets.

Theme and Topics

To better understand the origins and evolution of the universe and everything in it through study of high energy particles:

Fundamental physics of particle acceleration:

- Shock acceleration in SNRs, PWNe, and superbubbles, including key observables such as $e^{+/-}$, p populations and particle escape
- PWNe: "σ problem"
- Crab(like?) flares

Galaxy evolution and feedback:

- Trace CR source distribution and propagation in our Galaxy
- Distribution of star formation in the last ~ 1 Myr
- Acceleration, escape, and propagation of low(er) energy CRs responsible for majority of galactic chemistry and heating

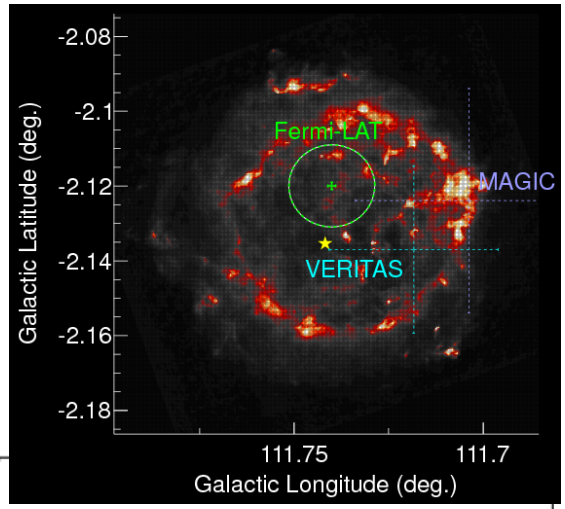
What other topics or themes should be included?

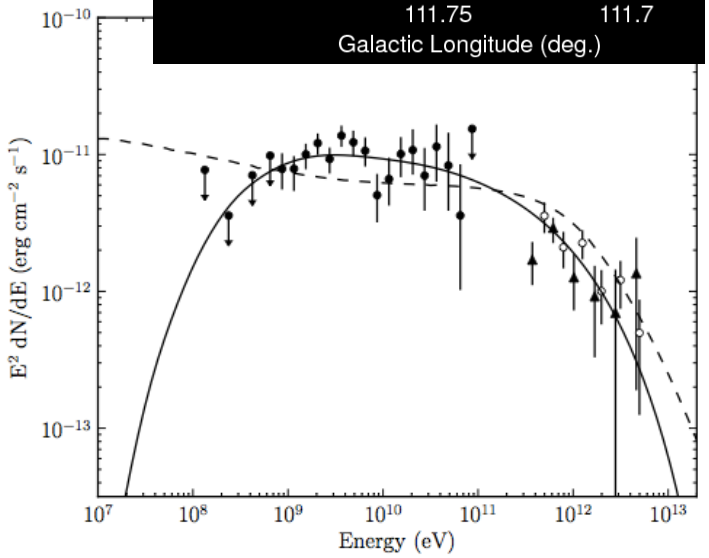
What other science topics are connected, at any energy?

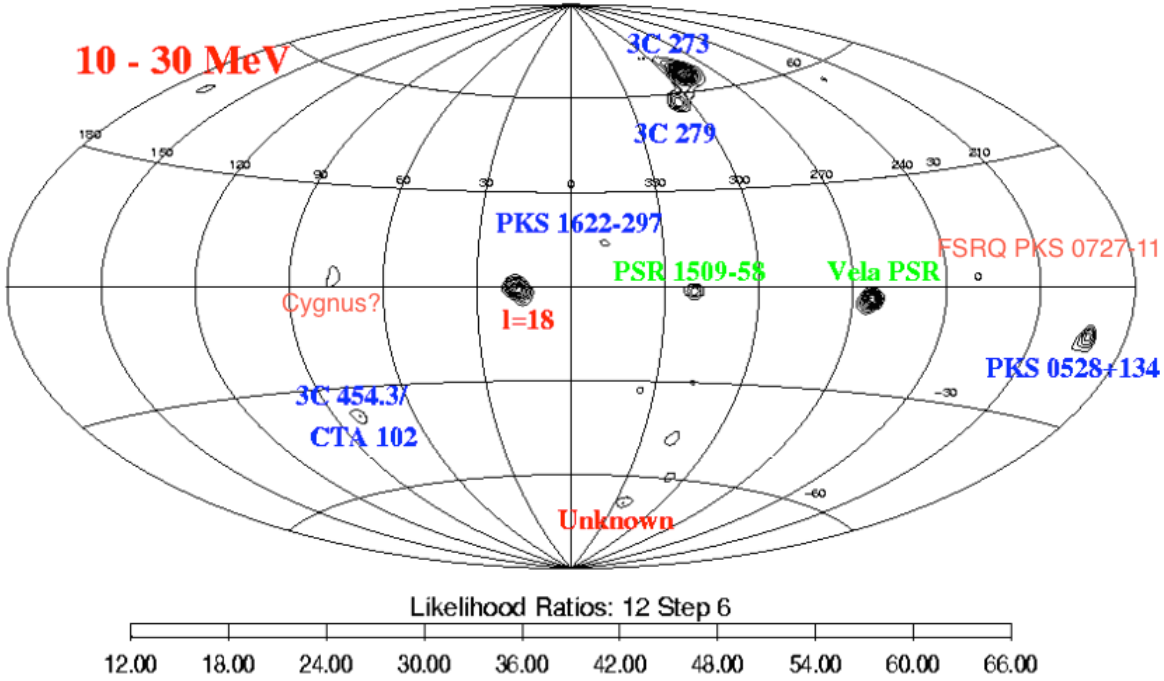
Contact me!

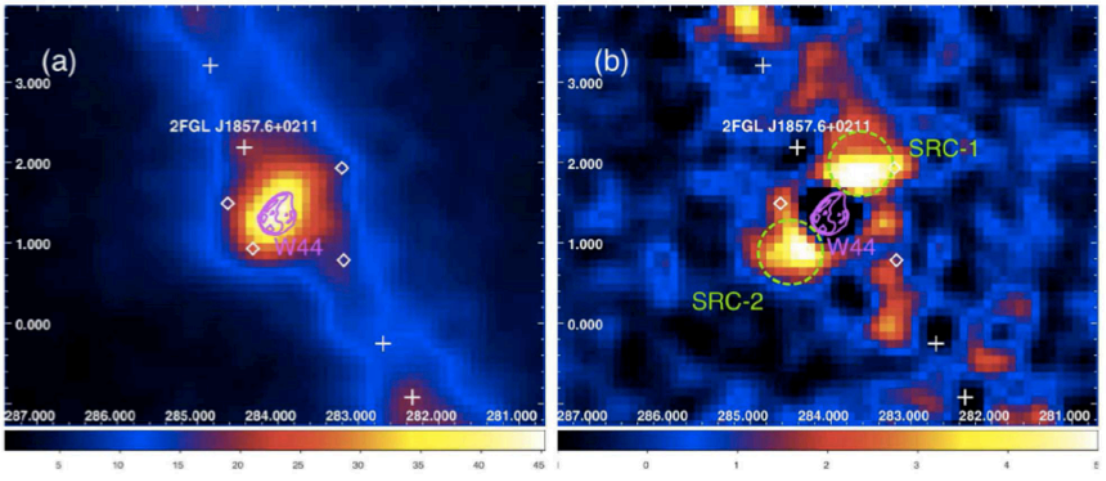
terri.j.brandt@gmail.com

Fermi-LAT shows hint of a “pion bump” in Cas A; Yuan+ 2013

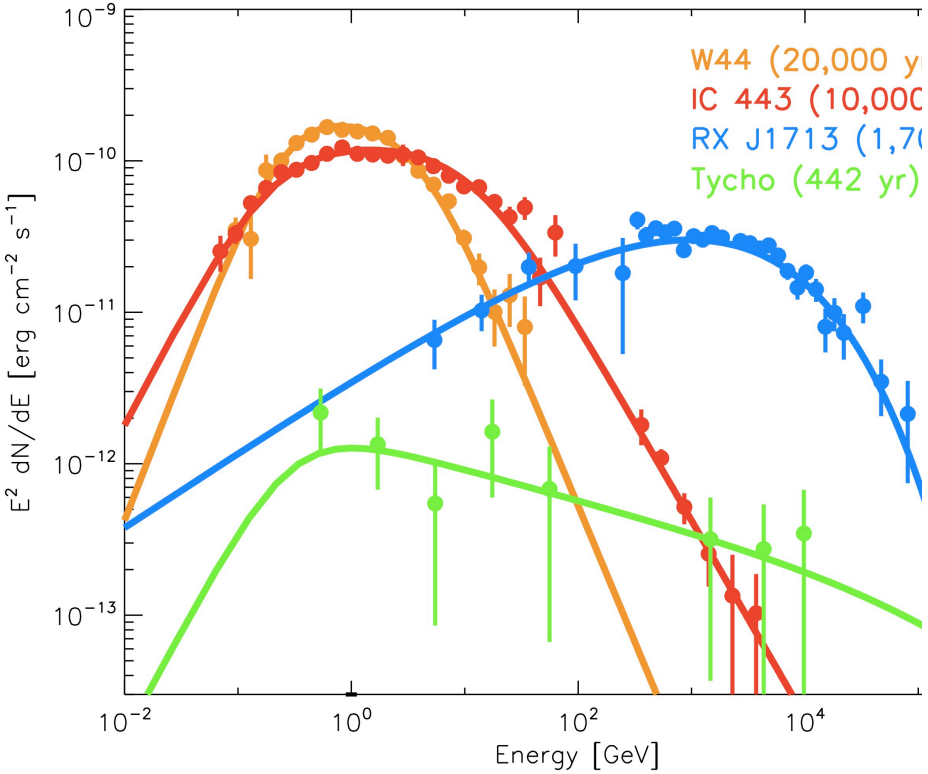


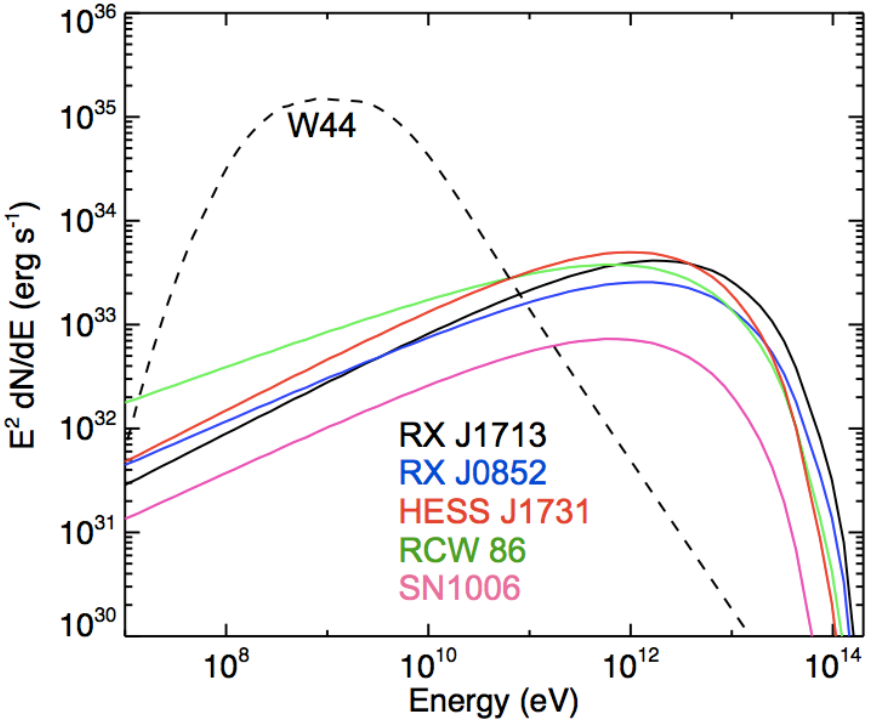


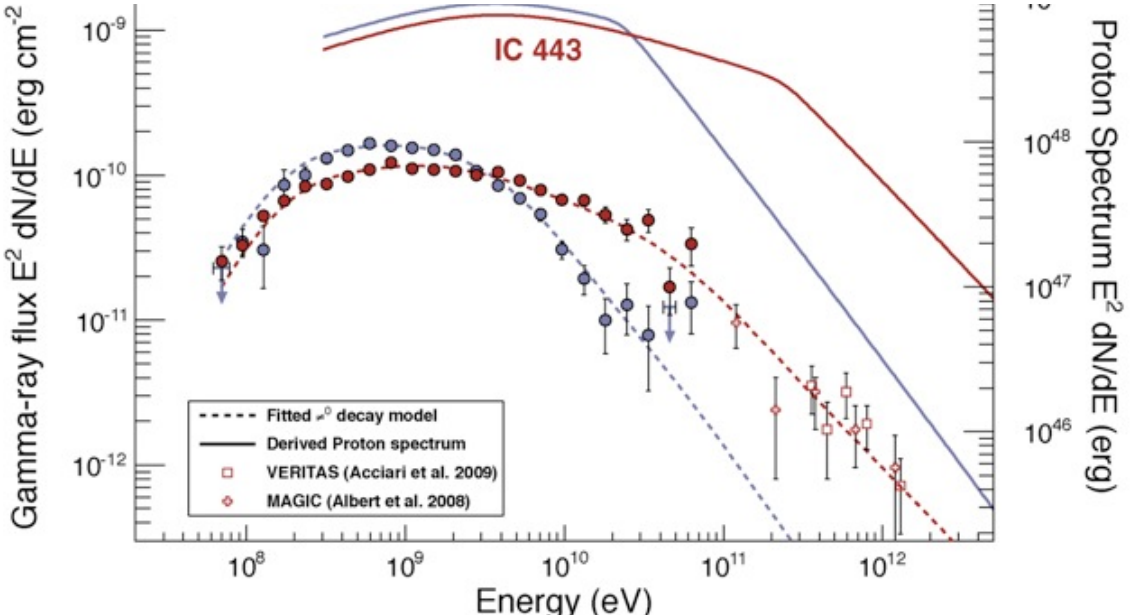




Uchiyama et al. 2012, ApJ 749, L35


W44 (20,000 y
IC 443 (10,000
RX J1713 (1,7(
Tycho (442 yr)
E² dN/dE [erg cm⁻² s⁻¹]
Energy [GeV]


W44
RX J1713
RX J0852
HESS J1731
RCW 86
SN1006
E² dN/dE (erg s⁻¹)
Energy (eV)


IC 443
Fitted π⁰ decay model
Derived Proton spectrum
VERITAS (Acciari et al. 2009)
MAGIC (Albert et al. 2008)
Gamma-ray flux E² dN/dE (erg cm⁻²
Proton Spectrum E² dN/dE (erg)
Energy (eV)

Conclusions:

The community roadmap will provide the best representation of the **scope of science** accessible in the gamma-ray window.

The roadmap will serve:

- as a **record** of the community's best estimates,
- as a **reference** for the current state of the art, and
- as a touchstone for the **future**.

Gamma-ray Roadmap:

Purpose:

- Prepare for the 2020 Decadal Review
- Articulate a common vision for the space-based gamma-ray community

The roadmap will:

- Define science objectives
- Define instrument requirements
- Summarize possible mission concepts

Currently have a table of science objectives and (notional) instrument requirements!
Have also begun tabulating mission concepts!

Gamma-ray Roadmap:

Purpose:

- Prepare for the 2020 Decadal Review
- Articulate a common vision for the space-based gamma-ray community

The roadmap will:

- Define science objectives
- Define instrument requirements
- Summarize possible mission concepts

Currently have a table of science objectives and (notional) instrument requirements!
Have also begun tabulating mission concepts!

Current Working Groups:

- X-Ray Binaries (Tomsick)
- Pulsars / Magnetars (Baring, Harding)
- SNR / PWNe (Brandt, Hewitt)
- Classical Novae (Cheung, Comiuk)
- Supernovae (Boggs, Grefensette, Leising)
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What other topics should be included?

Current Table!

GammaSIG: Science Topics, Science Requirements, and Instrument Requirements Tables

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7		Spatial:		Spectral:		Line/Continuum				
8	Topic	Coverage	Resolution (deg)	Energy Range	Resolution	Sensitivity (erg cm^-2 s^-1)	Timing?	Polarization?	Real-time Capability?	
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4 Science Requirements | Instrument Specs | Topic Key Members

https://docs.google.com/spreadsheets/d/12AHH5oOJO8NDu1FY3H1h3hclZBndGe8oJh-8vJBI8AE/edit?usp=sharing

Science Goals:

What are the key science questions in the following areas?

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Leverage work already done for AstroMeV! http://astromev.in2p3.fr/

What other topics should be included?

Instrument Requirements:

What are the **necessary** instrument requirements?
What are the **desired** requirements?
Where do the requirements overlap?
Capturing as:

Spatial:		**Spectral:**		**Sensitivity:**
Coverage	Resolution (deg)	Energy Range	Resolution	Line/ Continuum

Timing?	**Polarization?**	**Real-time Capability?**

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Technology Requirements:

The table will also help identify and motivate new technologies for strategic investment to enable us to build instruments that meet the requirements.

Strategic Astrophysics Technology (SAT) Awards

The Astrophysics Division (APD) at NASA Headquarters solicits proposals under the Strategic Astrophysics Technology/Technology Development for Physics of the Cosmos (SAT/TPCOS) program to mature key technologies for implementation in space flight missions. Selection of proposals for funding under the TPCOS 2010 solicitation were made based on the following factors: (1) the overall scientific and technical merit of the proposal; (2) the programmatic relevance of the proposed work; and (3) the cost reasonableness of the proposed work.

http://pcos.gsfc.nasa.gov/technology/strategic-technology-awards.php

Mission Concepts:

Straw missions:

- Abstract missions with notional platforms, technologies, and costs
- Drawn from the set of science goals and instrument requirements

Missions in development:

Drawn from current community efforts, with:

- defined science objectives
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Mission Concepts:

GammaSIG: Science Topics, Science Requirements, and Instrument Requirements Tables

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Mission	Energy Range [MeV]	Energy Resolution [DE/E]	Angular Resolution [deg]	FOV [sr]	Flux Sensitivity [MeV cm-2 s-1]		
TPCs (polarimetry)							
AdEPT	5-200	~30% @ 70 MeV	~0.6 @ 70 MeV	~2 pi	<3e-5		
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Current (for a benchmark)							
Fermi-LAT	20->3e10^5	(18/7)% @ 100/1000 MeV	~(3/0.04) @ 100(10000) MeV	~2.5	<1e-6		
DAMPE (launche	5 GeV – 10 TeV	1% at 800 GeV	0.1° at 100 GeV	~0.3 m^2 sr	lower than LAT: http://lanl.arxiv.org/abs/1407.4866		(for g-rays)
**This is not a complete list, feel free to add additional instruments that have been left off							

Science Requirements | Instrument Specs | Topic Key Members

Conclusions:

The community roadmap will provide the best representation of the scope of science accessible in the gamma-ray window.

The roadmap will serve:

- as a **record** of the community's best estimates,
- as a **reference** for the current state of the art, and
- as a touchstone for the **future**.

Future G-ray Missions: A Community Roadmap

Future Space-Based Gamma-ray Observatories Workshop
25 Mar 2016

Terri Brandt
NASA / Goddard

Future G-ray Missions: Science Objectives & Instrument requirements

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Gamma-ray Community Roadmap:

Purpose:

- Support planning for the 2020 **Decadal**
- Serve as a reference for all gamma-ray proposals
- Enable deeper connections **within** and **between communities**
- Articulate a common vision for the space-based gamma-ray community

The roadmap will:

- Define science objectives, linked via compelling, enduring **themes**
- Define instrument requirements
- Summarize possible mission concepts

by:

- Compiling compelling science topics that can be accomplished by keV to GeV and higher energy instruments for launch by NASA.
- Flowing science topics into instrument requirements for reference by community and reviewers alike.

Ensure the greatest breadth and accuracy through community input!

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by:

- Painting a landscape
- Showing how gamma-ray astrophysics naturally forms a key component

with a context obtained by:

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Gamma-ray Surveyor:

The roadmap will:

- Define compelling, enduring **themes** linking science objectives
- Define instrument requirements
- Summarize possible mission concept(s)

by:

- Painting a landscape: **Multimessenger and Time Domain Astrophysics?**
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with a context obtained by:

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Science Goals:

What are the key science questions in the following areas?

- X-Ray Binaries
- Pulsars / Magnetars
- SNR / PWNe
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- **What other topics should be included?**
- **Ideas for linking themes?**
  - Eg: To better understand the origins and evolution of the universe and everything in it through study of high energy particles.
- **What other science topics are connected, at any energy?**

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terri.j.brandt@gmail.com

Comments Share

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Explore: no recommendations

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Please add your instrument concept to and/or update the table!

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